IMAGES (Version 2002-1)

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INTRODUCTION

The IMAGES code is designed for use with TART in medical and industrial imaging applications. Specifically, TART can first be to used to transmit neutrons or photons through any object, and tally transmitted particles in binary files as they cross a z plane located behind the object. The IMAGES code can then to used to read the binary files and create x by y images of the density of transmitted radiation crossing the z plane, i.e., essentially "x-rays" of the transmission.

For the TART run a user can vary,
1) the definition of the object that radiation is transmitted through,
2) the type of radiation used: neutron or photon,
3) the energy of the radiation,
4) the spatial extend of the radiation
5) the orientation (direction) of the radiation

For the IMAGE run a user can vary,
1) the type of binary files read: neutron or photon
2) the x by y extent of the image
3) the pixel resolution of the image
4) gray scale or color image
5) linear or log radiation level scaling

RADIATION LEVEL SCALING

We assume that we have a uniform source (uniform in x and y extent) of radiation, directed at our object. The uncollided transmission through the object will then be,

S(x,y) = S Exp[- $\rho(x,y,z)$]

$$\rho(x,y,z) = \int_0^z \Sigma t(x,y,z')dz'$$

Where,

S - our uniform source
S(x,y) - the transmission
$\rho(x,y,z)$ - mean free paths of material at (x, y) between the source and tally z plane

Normalized to our uniform source strength we have,

S(x,y)/S = Exp[- $\Sigma t(x,y) * z$]

For linear radiation level scaling this expression is used to define the gray scale or color of our image. In which case we are scaling according to the attenuation between the source and our tally plane.

For log radiation level scaling we take the log of this expression and use it to define the gray scale or color of our image,

Log[S(x,y)/S] = [- $\Sigma t(x,y) * z$]

In which case we are scaling according to the number of mean free paths of material between the source and our tally plane.

In all cases we will actually be dealing with the total transmission, not just the uncollided. Nonetheless, hopefully you can understand the concept of plotting either the attenuated radiation or its log. For optically thinner (i.e., few mean free paths) material the attenuated results work quite well. For optically thicker material the log works quite well. As with all IMAGES options, the choice is yours to select what best meets your needs.

EXAMPLE COUPLED TART-IMAGES PROBLEM

THE TART PROBLEM

For details of the example problem, see the actual TART input deck below. As an example problem we will transmit radiation through 4 layers of material,

1) Inner most is a 20 cm radius sphere of lead
2) Next is 1 cm of iron; a cylinder 49 to 50 cm in radius
3) Next is 1 cm of iron; a sphere 99 to 100 cm in radius
4) Outer most 1 cm of water; a sphere 149-150 cm in radius

The source of radiation will be a circular disk 200 cm in radius. The radiation will be first neutrons and then photons (2 separate problems), 14.1 MeV monoenergetic, and monodirectional, pointed directly at the tally plate behind the object.

TYPICAL RUNNING TIME

For the example problem shown below TART transported over 10 million neutrons or photon per minute, so that each of the two TART problems (one neutron and one photon) with 20 million source particles each, took less than 2 minutes each to run on a PC.

If you are willing to invest more time in the TART calculations by transporting more source particles, your payback will be in clearer images that can be viewed to higher resolution when you subsequently run IMAGES; see the below examples using 10 and 100 million source particles.

EXAMPLE TART GEOMETRY

Shown below is a 3-D view of the geometry as shown by TARTCHEK. If you were to view this solid object all you would see is what is shown below, namely a sphere with a cylinder stuck through it, which isn't very informative.

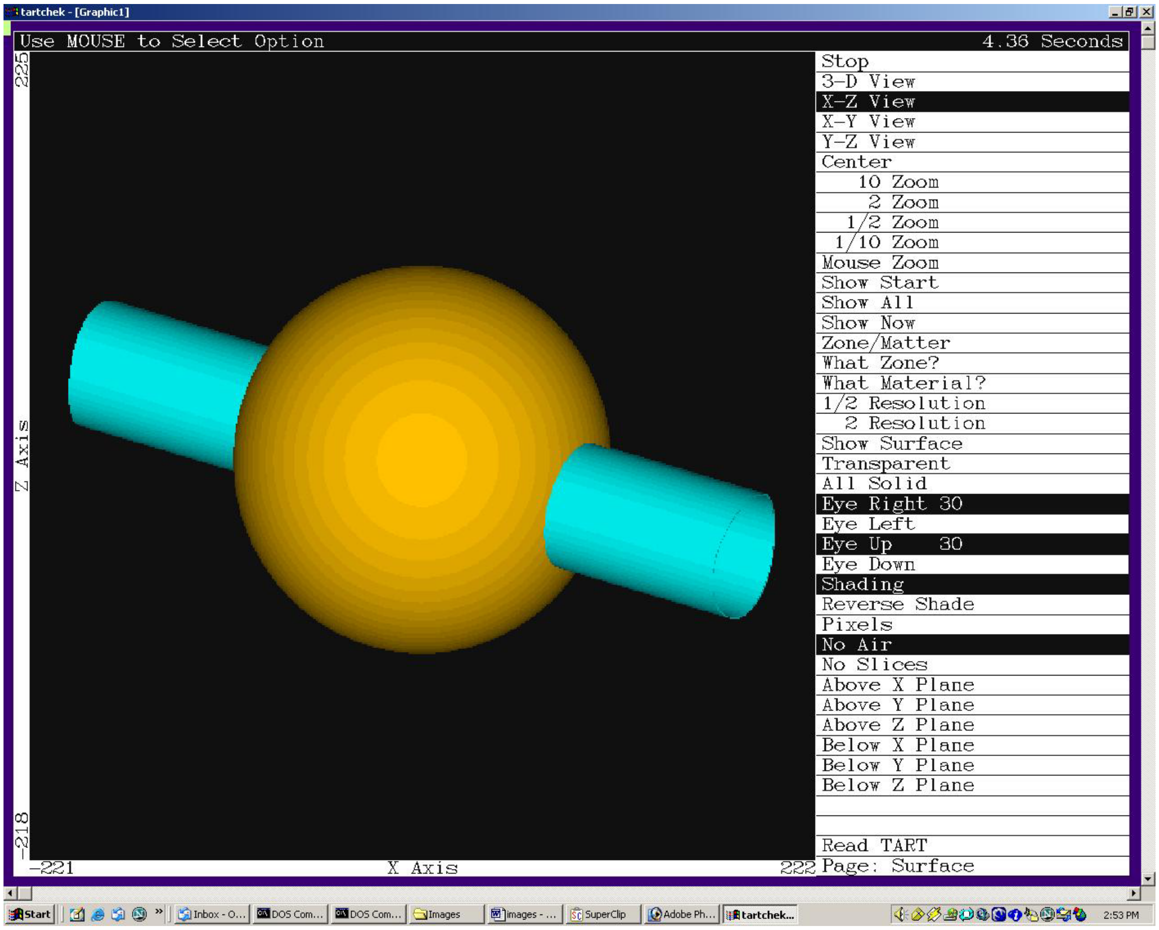

Fig 1: 3-D View of Solid Geometry

Shown below are a 2-D slice through the geometry and a 3-D sliced open view of half the geometry as shown by TARTCHEK. Using the 2-D view as a reference, the source will be emitted from your viewpoint toward the object, and we will tally the transmission through the object that reaches a plane located behind the object, directly away from your viewpoint.

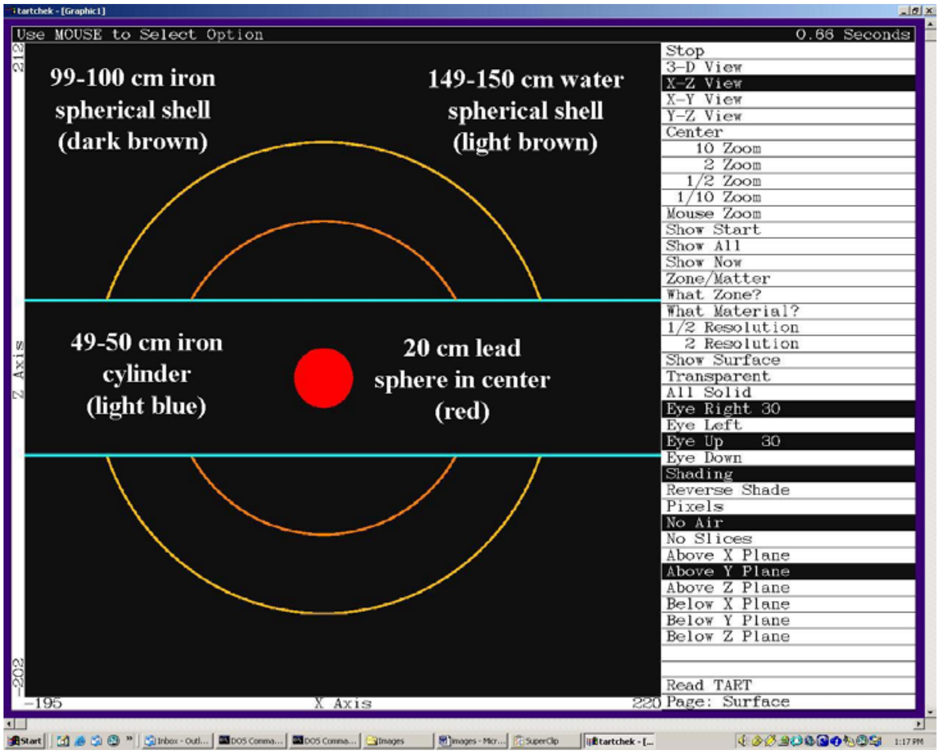

Fig. 2: 2-D Front Slice View of Object

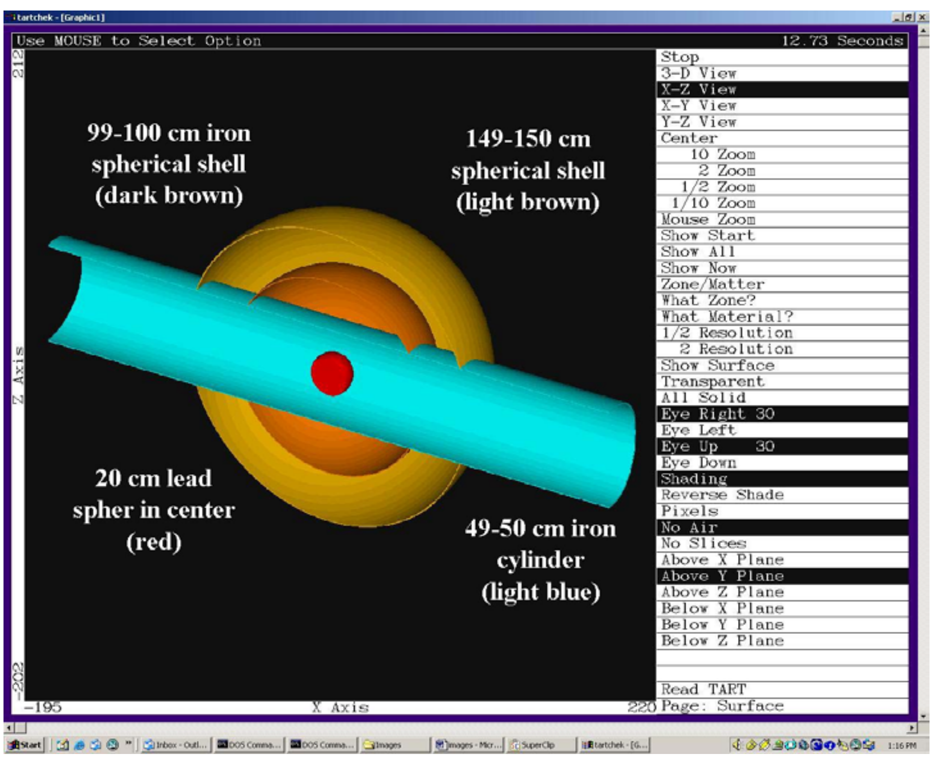

Fig. 3: 3-D Sliced Open Rotated View of Half the Object

PARTIAL AND FINISHED IMAGES

Each binary file contains about 50,000 histories. After reading 100 of these files (about 5 million histories) IMAGES will produce a plot identified as “Partial”, to indicate to you that there are still more histories to read. After all histories have been read the final plot is identified as “Finished”. Comparison of “Partial” and “Finished” plots provides valuable information about convergence, i.e., for a well converged plot you shouldn’t see much difference between the “Finished” plot and the immediately preceding “Partial” plot.

USE OF RESOLUTION

Please do not make the mistake of assuming you will get the “best” image using the highest resolution (presently set at 4,096 by 4096). There is a trade off between resolution and average number of histories per pixel that limits resolution. For example, for the following example problems we use 20 million histories. For a 500 by 500 plot that is 80 histories per pixel, for a 1000 by 1000 that is 20 histories per pixel and for 2000 by 2000 that is only 5 histories per pixel. Allowing for attenuation, 5 histories per pixel should result in pretty noisy results. If you want high resolution you will have to use TART to transport more source particles, which means longer TART runs.

To illustrate the tradeoff between resolution and number of histories, the following figures illustrate images using four different resolutions (250, 500, 1000, 2000) and two different numbers of histories (10 and 100 million neutrons). Note, that to run 10 million particles took TART about 1 minute, and for 100 million particles about 10 minutes; that’s the penalty that you pay if you need to run more particles. There is an additional penalty when running IMAGES in that a higher resolution image takes longer to plot; often the IMAGE plotting time will be longer than the TART calculation.

From the following figures you will note that for 10 million particles there is a great deal of variation in the images as resolution is changed. For 100 million particles there is less variation. This illustrates that the images converge (saturate) when the number of histories per pixel is increased. Using 10 million neutrons, in the first figure the neutrons per pixel varies from 160 (250 x 250) to 2.5 (2000 x 2000). Using 100 millions, in the second figure the neutrons per pixel varies from 1600 (250 x 250) to 25 (2000 x 2000).

The below figure compare results for exactly the same neutron problem using 250, 500, 1000, and 2000 pixels using only **10 million** source neutrons.

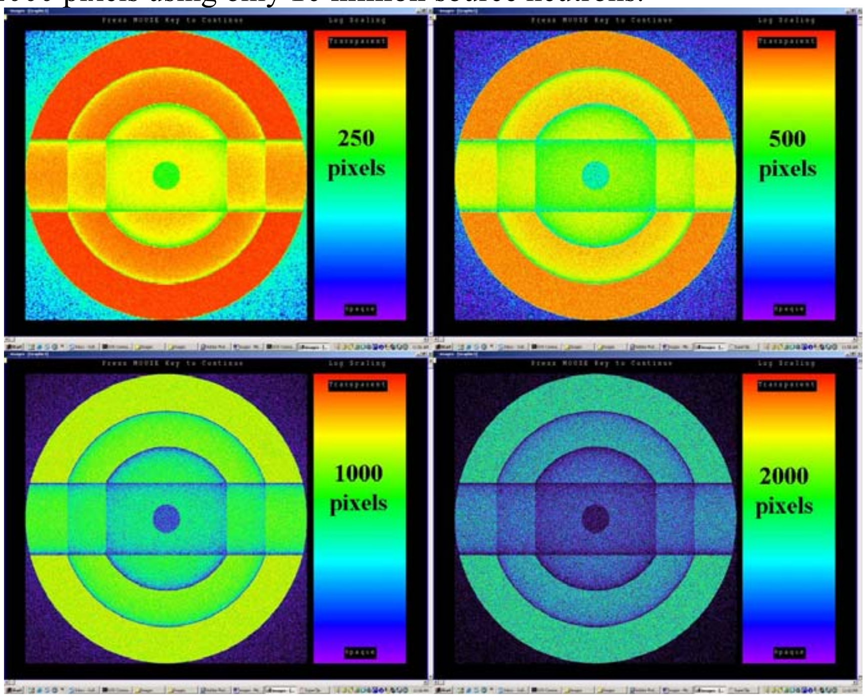

Fig. 4: Results versus resolution, 10 million particles

The below figure compare results for exactly the same neutron problem using 250, 500, 1000, and 2000 pixels using **100 million** source neutrons.

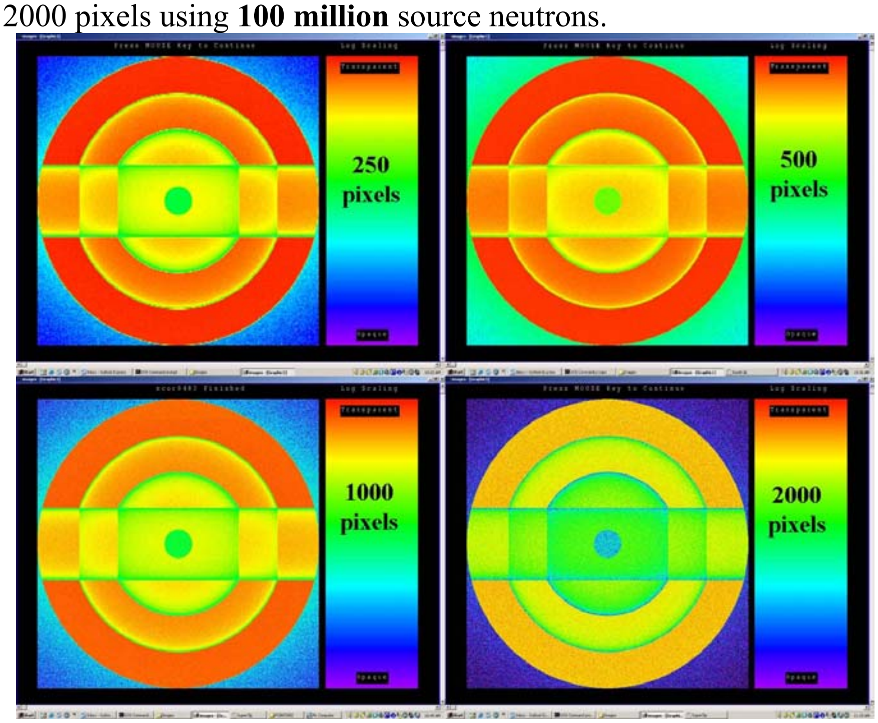

Fig. 5: Results versus resolution, 100 million particles

THE IMAGES PROBLEM

For the IMAGES problem we read the photon and neutron binary files created by the TART problem described above, and "look at" the results using various input options. Below is a copy of the IMAGES.INP input parameter file. Each line of input creates one image. Input terminates at the end of this file, or if there is an error in the input. In this case the ninth line that starts with ==== will result in an input error and cause the code to stop.

The below input will create the eight images shown below. All will use a view,
X = -200 to +200 cm
Y = -200 to +200 cm
and 500 pixels in each dimension, i.e., a 500 x 500 view
The four images for photons and neutrons illustrate the use of the input options for,
Gray scale or color
Linear or log radiation level scaling

```
photon     -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 0 0
photon     -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 0 1
photon     -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 1 0
photon     -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 1 1
neutron    -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 0 0
neutron    -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 0 1
neutron    -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 1 0
neutron    -2.0000d+02 2.0000d+02-2.0000d+02 2.0000d+02        500 1 1
====(NOTHING BELOW THIS LINE IS READ)====================================
```

```
     INPUT PARAMETERS
     ================
     LINE    COLUMNS    FORMAT    DESCRIPTION
     ======================================
       1      1-11       A11      TYPE OF DATA
                                  neutron
                                  photon
                                  OTHERWISE = ERROR
       1      12-22      d11.4    XMIN
              23-33      d11.4    XMAX
              34-44      d11.4    YMIN
              45-55      d11.4    YMAX
              56-66       I11     # of Pixels (4096 max.)
              67-68       I2      = 0 = gray scale/otherwise = color
              69-70       I2      = 0 = linear scale/otherwise = log
```

IMAGES RESULTS

The below figure attempts to explain what you should look for in the following figures. If we have a good, clear image we should be able to see all four layers of material of the object, starting from the lead sphere 20 cm in radius at the center, followed by an iron cylinder 1 cm thick from 49 to 50 cm in radius, followed by an iron spherical shell 1 cm thick from 99 to 100 cm in radius, followed by a water spherical shell 1 cm thick from 149 to 150 cm in radius.

Beyond the 150 cm radius water sphere we see the most intense transmission corresponding to the unattenuated source from 150 to 200 cm in radius, completely outside of the object. Beyond 200 cm out to the edge of the 400 by 400 cm plane we see low level radiation due to radiation that has been scattered from the source beam, and then crosses our tally plane within the 400 by 400 cm image area.

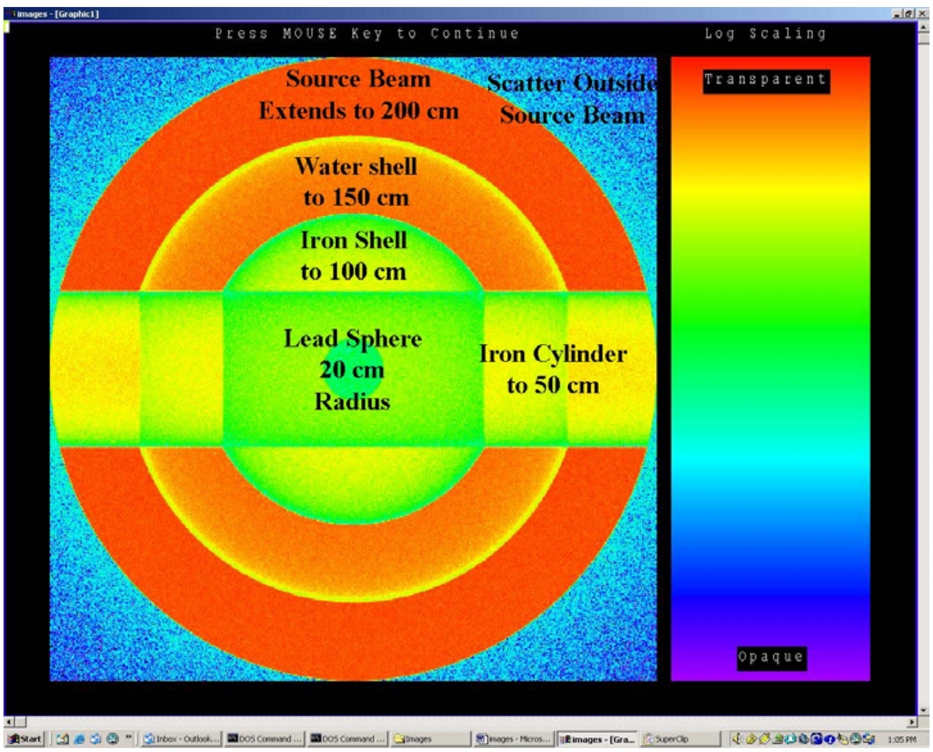

Fig. 6: What you should look for

I won’t comment on the clarity and useful of the following figures; I’ll let you be the judge of what best meets your needs. You can decide should you use neutrons or photons, what energy should they have, what’s, “best” gray scale or color? Linear or log radiation level scaling? Hopefully you can use IMAGES to answer these questions.

The following 8 figures illustrate results for exactly the same object, with 14.1 MeV particles incident, directly (monodirectional), varying,

1) photons (first 4 figures) or neutrons (next 4 figures)
2) gray scale or color plot
3) linear or log radiation level scaling

Fig. 7: photons, gray scale, linear radiation level

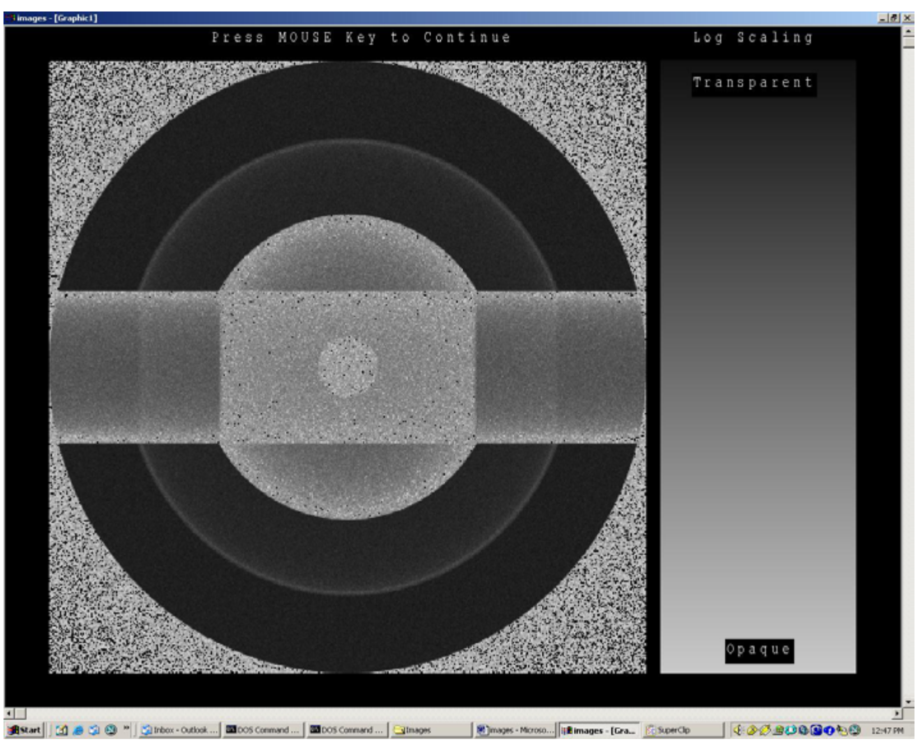

Fig. 8: photons, gray scale, log radiation level

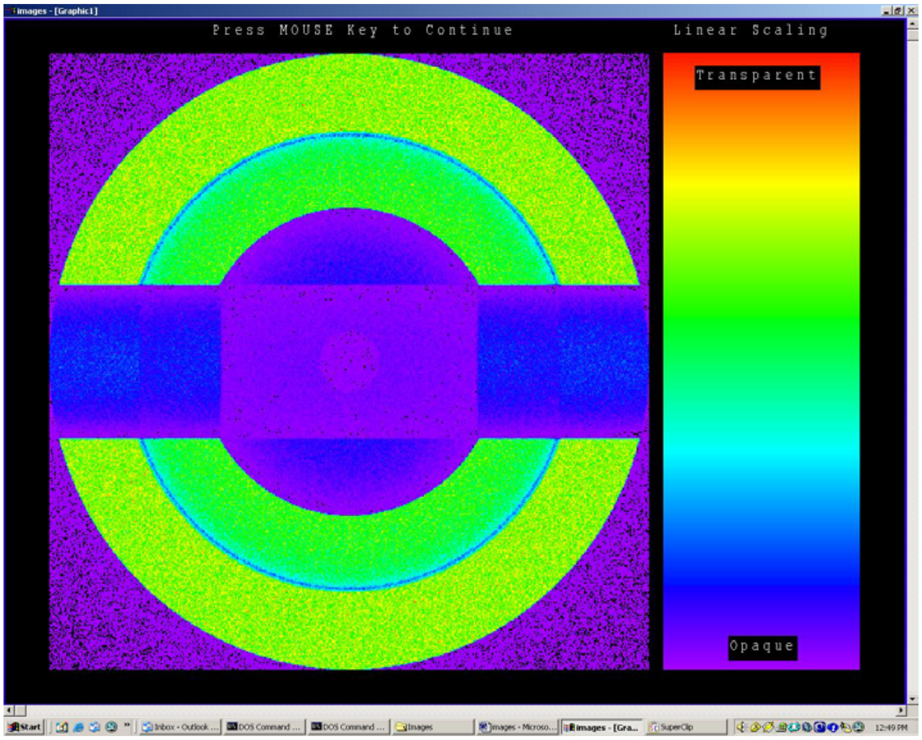

Fig. 9: photons, color, linear radiation level

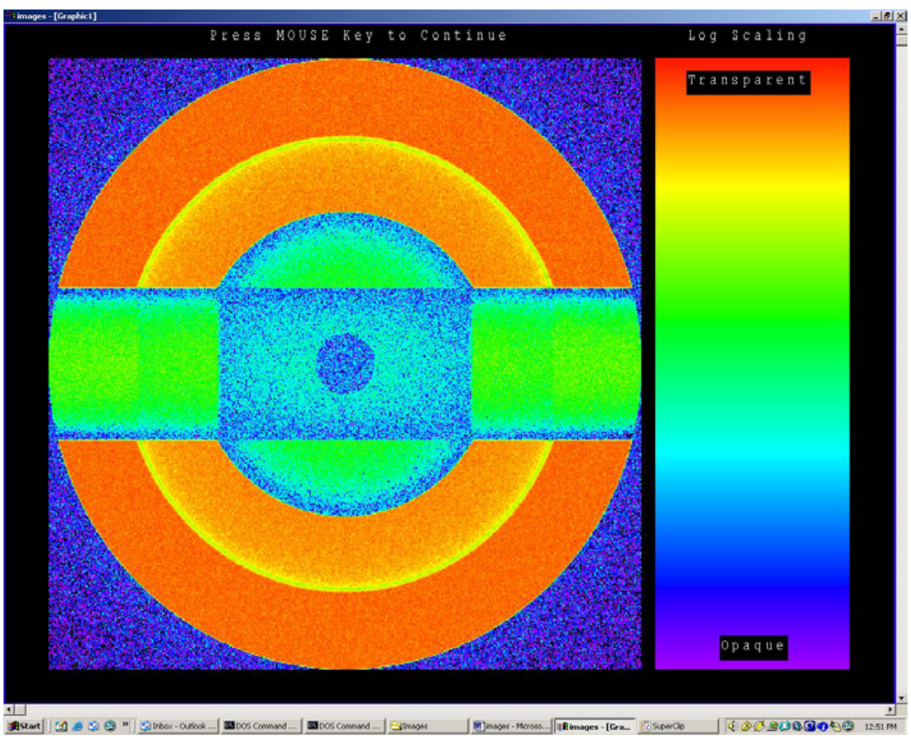

Fig. 10: photons, color, log radiation level

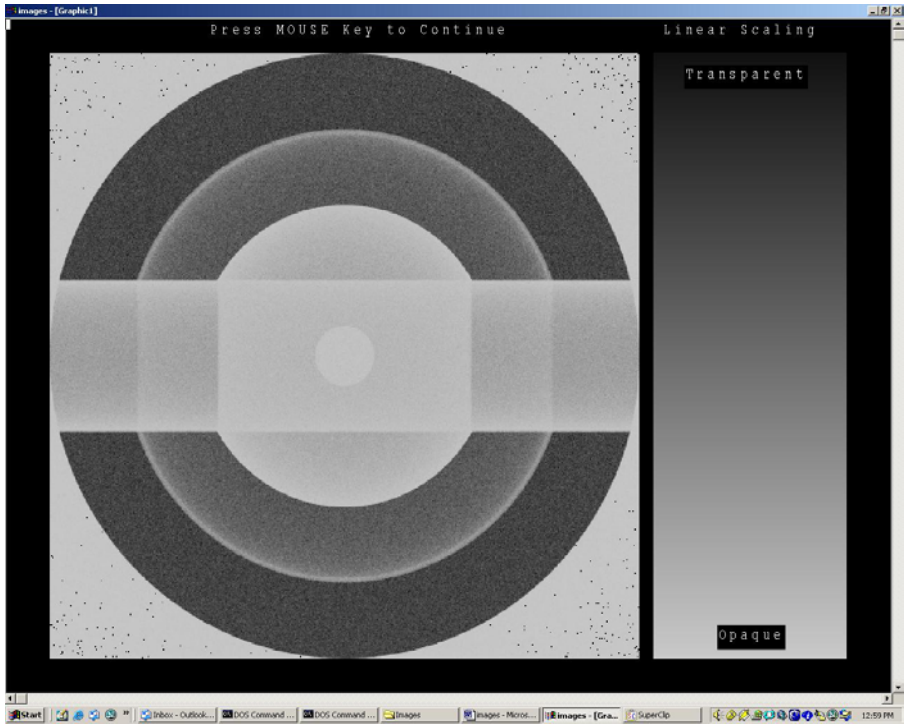

Fig. 11: neutrons, gray scale, linear radiation level

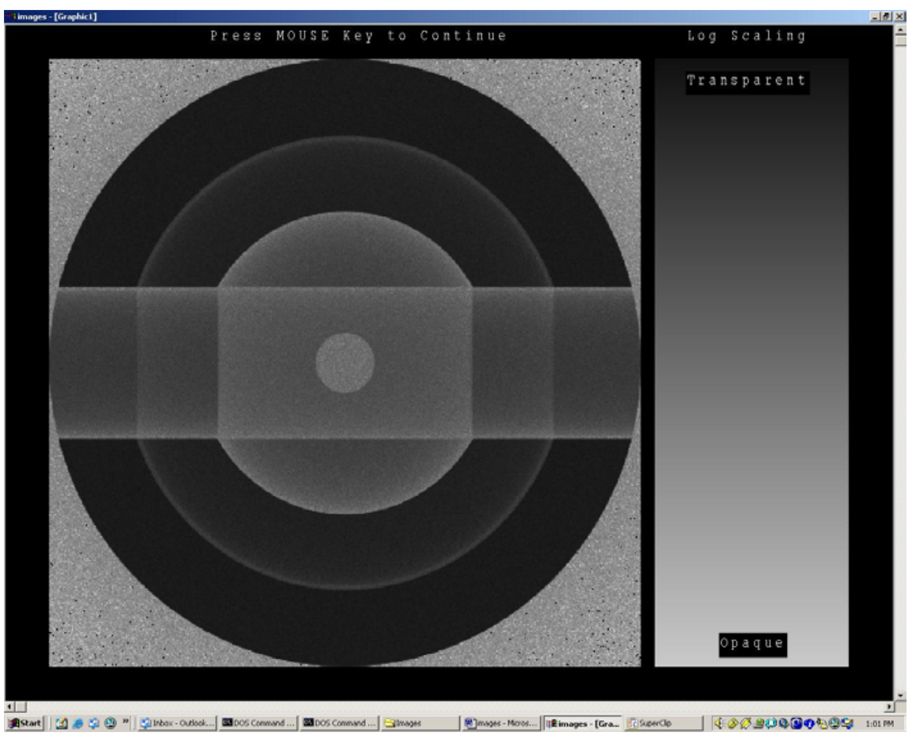

Fig. 12: neutrons, gray scale, log radiation level

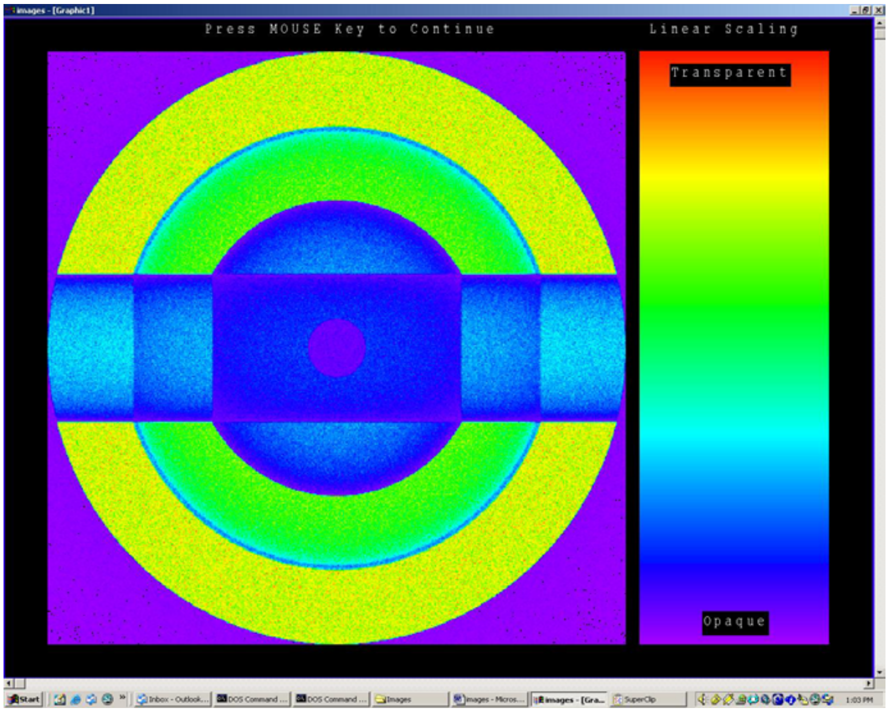

Fig. 13: neutrons, color, linear radiation level

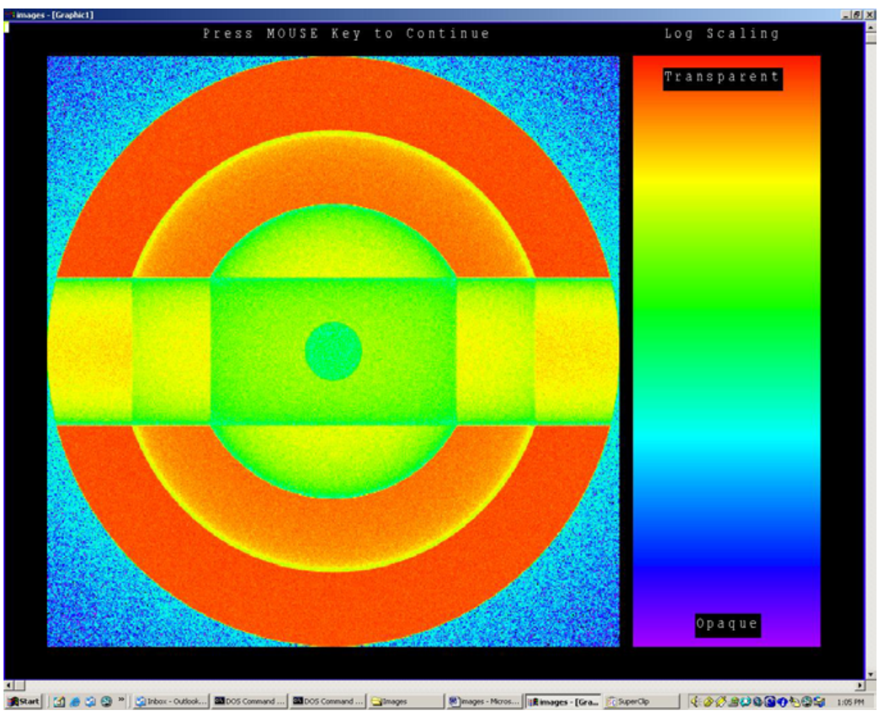

Fig. 14: neutrons, color, log radiation level

EXAMPLE TART INPUT PROBLEM

```
* ============================================================
*
* This input deck includes 2 TART input problems to illustrate
* how to use the TART utility code IMAGES for neutrons (first
* problem) and photons (second problem).
*
* Each problem has a cylinderical disk emitting particles (neutrons
* or photons) directly (monodirectional) at an object. Everything that
* passes through the object is tallied in zone 9, as it passes a
* z plane - tally is into a binary file that can later be read by
* the IMAGES code - it will plot the results on an (x, y) plane, just
* like an x-ray - which is what this is.
*
* You can experiment to learn how to use IMAGES, and find out what
* works "BEST" - neutrons or photons? What incident energy? What's
* the best resolution (pixels) to use with IMAGES, etc., etc., etc.,
* use your imagination.
*
* ============================================================
name neutron image
box 32 neutron image
* ============================================================
*
* Geometry
*
* ============================================================
sphere    1   20
cylx      2   49
cylx      3   50
sphere    4   99
sphere    5  100
zplane    6 -300
zplane    7  300
cylz      8  300
sphere    9  149
sphere   10  150
* ============================================================
* inside inner sphere = lead
jb   1    1
matl 1    18.6    1.0 82000
matz 1    1
* inside inner cylinder, outside inner sphere = air
jb   2   -1    2       8
matl 2    1.0d-4  1.0  7014
matz 2    2
* between cylinders = iron
jb   3   -2    3       8
matl 3    8.6     1.0 26000
matz 3    3
* inside middle sphere, outside cylinders = air
jb   4    4   -3
matz 2    4
* between sphere, outside cylinders = iron
jb   5   -4    5   -3
```

```
matz 3    5
* air region
jb   6   -6    7    8   -3   -10
matz 2    6
* air
jb  10    9       -5   -3
matz 2   10
* outer spherical shell - water
jb  11   -9   10  -5   -3
matl  4   1.0    2.0  1001   1.0   8016
matz  4  11
*
*  outside world is empty
*
* outside bounding z cylinder, between planes
jb   7   -6    7   -8
* behind source
jb   8    6
* behind object = tally zone
jb   9   -7
* ==========================================================
*
* Source
*
* ==========================================================
* 14.1 MeV, monoenergetic source energy
sentl     4   14.1
* Monodirectional, directly at tally plate
*               dcos      cos
sentl     6    0.0   7   1.0
* circular source 0 to 200 cm in radius, 290 cm from origin
*          #   ri    ro      z0     dz    x0    y0
source2   6   0.0   200  -290   0.0   0.0   0.0
* ==========================================================
*
* Definition of Running Conditions and Output Edit Options
*
* ==========================================================
*  1) Transport (neutrons and/or photons) (0)
sentl   1     1
*  2) Number of Batches
sentl   2   100
*  3) Particles per Batch
sentl   3   200000
* tally to binary file
ltype  12   9
* next job
sentl  24   1
end
* ==========================================================
name photon image
box 32 photon image
* ==========================================================
*
* Geometry
*
```

```
* ===========================================================
sphere    1   20
cylx      2   47
cylx      3   50
sphere    4   97
sphere    5  100
zplane    6 -300
zplane    7  300
cylz      8  300
sphere    9  147
sphere   10  150
* ===========================================================
* inside inner sphere = lead
jb   1    1
matl 1    18.6    1.0 82000
matz 1    1
* inside inner cylinder, outside inner sphere = air
jb   2   -1    2       8
matl 2    1.0d-4  1.0  7014
matz 2    2
* between cylinders = iron
jb   3   -2    3       8
matl 3    8.6     1.0 26000
matz 3    3
* inside middle sphere, outside cylinders = air
jb   4    4   -3
matz 2    4
* between sphere, outside cylinders = iron
jb   5   -4    5   -3
matz 3    5
* air region
jb   6   -6    7    8   -3   -10
matz 2    6
* air
jb  10    9       -5   -3
matz 2   10
* water
jb  11   -9   10  -5   -3
matl  4   1.0    2.0  1001   1.0   8016
matz  4  11
*
*  outside world is empty
*
* outside bounding z cylinder, between planes
jb   7   -6    7   -8
* behind source
jb   8    6
* behind object = tally zone
jb   9   -7
* ===========================================================
*
* Source
*
* ===========================================================
* 14.1 MeV, monoenergetic source energy
sentl    17   14.1
```

```
* Monodirectional, directly at tally plate
*              dcos      cos
sentl    41    0.0  42   1.0
* circular source 0 to 200 cm in radius, 290 cm from origin
*         #   ri    ro     z0     dz    x0    y0
s2g       6   0.0   200  -290   0.0   0.0   0.0
* ============================================================
*
* Definition of Running Conditions and Output Edit Options
*
* ============================================================
*  1) Transport (neutrons and/or photons) (0)
sentl   1     2
*  2) Number of Batches
sentl   2   100
*  3) Particles per Batch
sentl   3   200000
* tally to binary file
ltypeg 12   9
* next job
sentl  24   0
end
```